Cratering Rates on Synchronously Rotating Satellites

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Impact cratering of synchronously rotating satellites is expected to occur faster on the leading hemisphere than on the trailing hemisphere because the orbital velocity of the satellite around the planet is generally large compared to the space velocities of comets and asteroids. The relationship between comets and moons is broadly akin to that between flies and windshields. As it is with cars, the predicted asymmetry is large, with cratering rates at the apex of motion (the center of the leading hemisphere) typically 30–80 times greater than at the antapex. However, the expected asymmetry is at best poorly expressed on actual satellites, with the alarming exception of Triton, where the observed asymmetry is apparently too great. The failure to observe the seemingly inevitable suggests that some of these satellites have led, and may still be leading, interesting lives.

This study used a suite of Monte Carlo simulations to better determine how cratering rates vary across the surfaces of synchronous satellites. The method generates orbits randomly from ancestral distributions that arguably are isotropic, or nearly so; assigns to each orbit an impact probability and a possible impact site and appropriate crater diameter; while also allowing practical treatment of many effects that would be dauntingly difficult to treat analytically. An empirical fit to the suite of numerical experiments is that the cratering rate is

$$\dot{N} \propto \left(1 + \frac{v_{\rm orb}}{\sqrt{2v_{\rm orb}^2 + v_\infty^2}}\cos\beta\right)^{2.0+0.47\gamma}$$

where $v_{\rm orb}$ refers to the circular orbital velocity of the satellite and v_∞ refers to the characteristic encounter velocity of the ecliptic comet with the planet; the angle β is the angular distance measured from the apex of motion; and the parameter γ is the power law exponent describing the assumed cumulative size distribution of the impactors, $N(>d) \propto d^{-\gamma}$, where d is diameter. The expression works well for $1 < \gamma < 4$; real solar-system populations typically have $1.5 < \gamma < 3$.

As noted previously, the predicted cratering asymmetries are not seen, in fact. Most synchronous satellites are effectively saturated with impact craters, for which no signature of a leading/trailing cratering asymmetry is to be expected. The three interesting exceptions are Ganymede and Europa, moons of Jupiter, and Triton, chief moon of Neptune. Europa has few impact craters and no obvious leading/trailing asymmetry. But this is not surprising, because Europa's icy shell is decoupled from the interior by a liquid water ocean: it would be relatively easy for the shell to rotate nonsynchronously. Ganymede is a more interesting case. Careful analysis reveals that Ganymede does preserve a fourfold asymmetry between fore and aft. This asymmetry is much less than the 60-fold asymmetry expected, but it is in the right direction: a possible interpretation is that Ganymede once rotated nonsynchronously but no longer does. This finding in turn implicates a once-thicker liquid water ocean for Ganymede, a conclusion in harmony with other clues that Ganymede was once much more like Europa than it is now.

Finally, Triton revolves in a retrograde orbit around Neptune. It appears to be a captured comet that melted as its orbit tidally evolved from a highly eccentric ellipse to a circle. Triton has very few craters. Its surface is obviously geologically young, probably no older than Europa's. Essentially all its impact craters are on its leading hemisphere. In particular, a lack of craters near $\beta = 90$ degrees appears to be real, because this region (facing Neptune) was the part of Triton seen best by the Voyager 2 spacecraft. This cratering pattern is too asymmetric to be accounted for by comets or other objects that orbit the sun. Required, rather, are objects in prograde orbit around Neptune. Such objects would strike Triton mostly head-on, and the resulting craters would be confined mostly to the leading hemisphere. The origin of the implied swarm of prograde, Neptune-orbiting debris is an open question. The alternative explanation is that Triton has been capriciously resurfaced so as to appear, from the one viewpoint of the Voyager 2, as if it had run face-first into a swarm of debris.

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EXOBIOLOGY

A Greenhouse Co-Laboratory

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The Ames Microbial Ecology/Biogeochemistry Research Lab, in combination with the ScienceDesk team, has made significant progress in realizing a greenhouse "co-laboratory," which will be shared by members of the NASA Astrobiology Institute's Early Microbial Ecosystems Research Group (EMERG). (See figure 1.) The greenhouse facility is being used to maintain and perform manipulations of field-collected microbial mats. Microbial mats, extant representatives of Earth's earliest ecosystems, are highly dynamic communities of microorganisms that exhibit extremely high rates of metabolic processes. Maintaining the structure and function of these communities outside the natural environment is, therefore, a challenge. Using the greenhouse constructed on the roof of Building N239, mats that resemble naturally occurring communities have been maintained over a year after field collection. In FY00 it was determined that the greenhouse-maintained mats sustain natural rates of biogeochemical processes. This facility, therefore, is useful to support continued measurements of the rates and conditions under which various trace-gases are emitted and/or consumed by microbial mats and stromatolites. The greenhouse mats will be used to investigate the effects of early Earth environmental conditions on the rates of trace-gas production and consumption in the microbial mats, a period of Earth's history no longer available to us for direct measurement. These measurements are also relevant to the search for life on extrasolar planets, where the most promising search strategy involves the detection of possibly biogenic gases using infrared spectrometry. Space-based interferometers, such as the Terrestrial Planet Finder, should be able to resolve the spectra of several biologically important trace gases in the atmospheres of extrasolar planets, possibly within 10–15 years.

The greenhouse represents a unique facility and a unique resource to be shared among EMERG team members. The scientific objectives of the team require multiple collaborators to conduct and analyze measurements of mat parameters on a frequent basis over many weeks. However, pragmatics and funding constraints inhibit the productivity of the distributed team and prevent full utilization of the greenhouse. The construction of a